A Novel Manufacturing Process of Lightweight Automotive Seats
- Integration of Additive Manufacturing and Reinforced Polymer Composite

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Ford Motor Company

06/22/2022

Project ID#: mat210

Overview

Timeline

- ➢ Project start date: Feb 2020
- ➢ Project end date: Sep 2022
- ➢ Percent complete: 70%

Barriers and Targets

- ➢ Vehicle light-weighting
- ➢ Seatback: high-performance requirement due to safety under crash incident
- ➢ Replacement of current metal frame with lightweight composite

Budget

- ➢ DOE project funding: $500K
- ➢ Partner's in-kind contribution: $500K

Partners

- ➢ Ford Motor Company (Industry Partner)
  Lead: Patrick Blanchard

Relevance/Objectives

Overall Objectives

To develop a novel manufacturing technique to produce lightweight car seats by combining AM and overmolding techniques

VTO's Mission

Support research, development (R&D), and deployment of efficient and sustainable transportation technologies that will improve efficiency, fuel economy, and enable America to use less petroleum

The newly developed process will:

- Allow for new lightweight seat designs that cannot be achieved through any conventional processing methods.
- Produce seats with **tailored microstructure and performance**.
- Explore an **in-line integration of sensing and smart systems** that will be used for process monitoring. The collected data will be used within an Artificial Intelligence (AI) framework for discontinuous reinforced composite manufacturing processes in order to optimize the processing conditions and part performance.

Tasks:

Stage I: Manufacturing of the seat back panel via large scale AM

- A preform from AM for a seat back panel with highly aligned fibers along the deposition direction.
- Multiple materials with different mechanical performances.

Stage II: Over-molding process

- Integration of the seat back panel preform, molding of the reinforcement features, and placement of the metal struts

Milestones

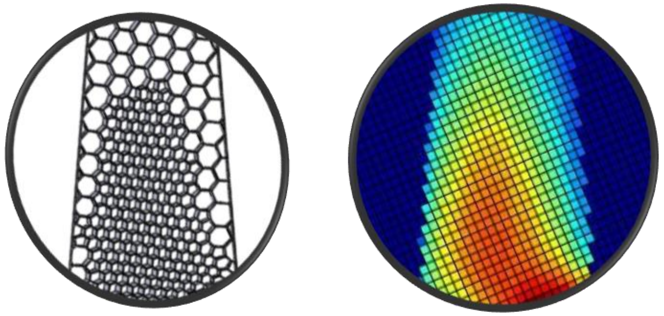
Phase No.	Task No.	Task Name	Duration (Months) (Start) (Finish)		Responsible Party
I	1	Project planning and management	0	33	Ford Motor Company/ORNL
I	2	Establish the required properties and the design aspects for the car seat	0	1	Ford Motor Company
I	3	New lightweight seat design through topology optimization	1	8	Ford Motor Company/ORNL
I	4	AM metal inserts for the recliner connection	4	12	ORNL
II	5	Subcomponent design of seatback with the metal insert	12	18	Ford Motor Company/ORNL
II	6	Automation technology development for AM polymer composite preform overmolding	19	27	Ford Motor Company/ORNL
II	7	Mechanical characterization of the overmolded parts with various design parameters for mechanical bonding and performance	22	29	ORNL
II	8	Exploration of integrating smart sensing system for pressure/temperature and framework for AI technology	26	31	Ford Motor Company/ORNL
II	9	Final performance evaluation of the seatback assemblies via simulation	28	33	Ford Motor Company

PROGRESS

Approach

- Metal lattice structure via AM
  - Design of lattice structure
  - Adaptive lattice generation
- Polymer Composite AM Preform
  - Fiber orientation control
  - Tailored toolpath direction
- AM – CM Process
  - Strengthening via void reduction
- Composite overmolding
  - Maximize the advantages from dissimilar materials (e.g., Metal / composite)

Adaptive Core Technology for Topology Optimization of IM/CM Mold



Seat Back Reinforcement Ribs Panel

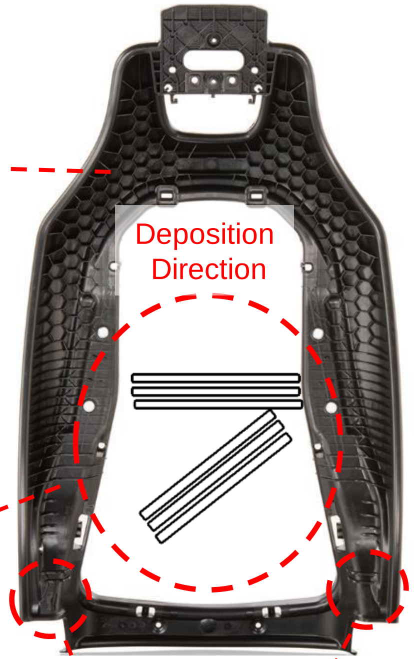
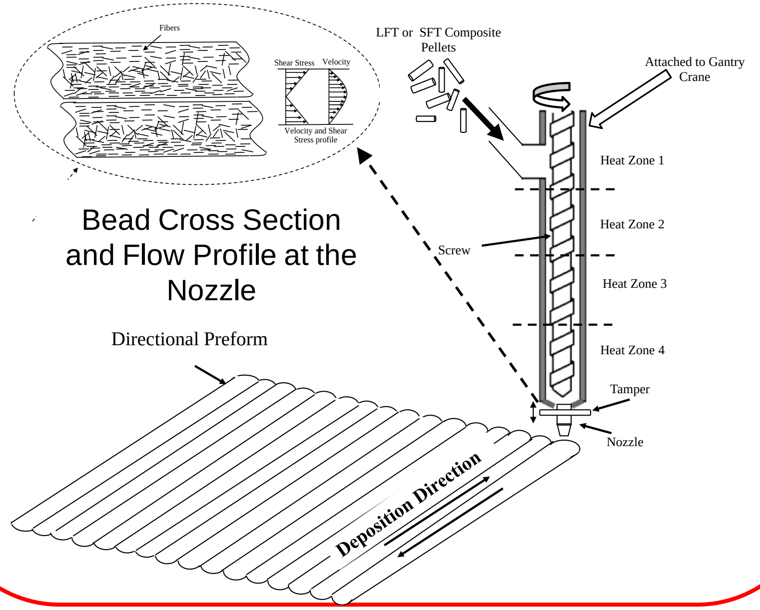
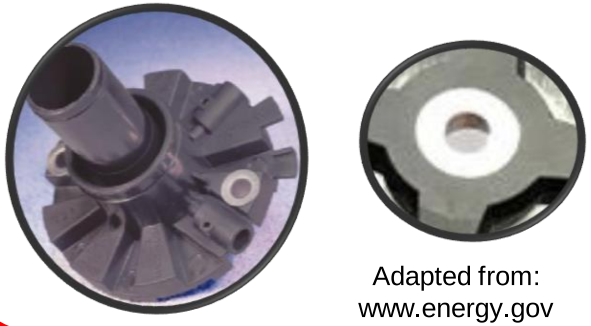


Image from: automotive.basf.com

Using Large Scale AM for Preform



Over Molding of Metal Inserts for Recliner Connections

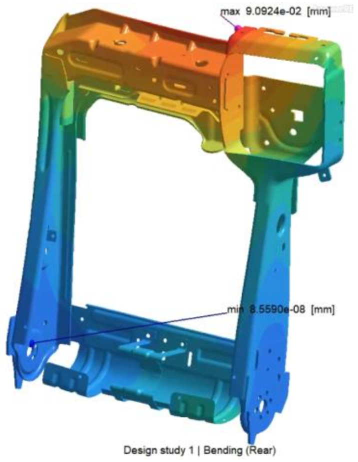


Adapted from: www.energy.gov

Accomplishments: Lightweight seat design – Stiffness Comparison

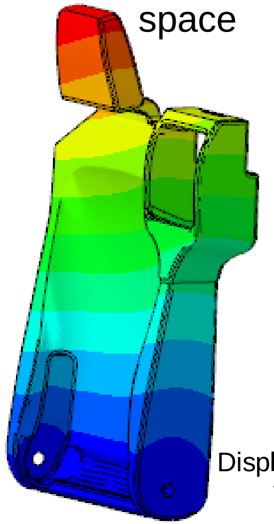
- ➢ Composite alone does not provide enough stiffness.
  - Composite with a fully filled space: 260 – 320 N/mm vs. Metal: 1100 N/mm
- ➢ Composite combined with a metal insert significantly increases the stiffness.
  - 320 N/mm (w/o metal) → 930 N/mm (w/ metal)
- ➢ Optimization of metal insert highly affects the stiffness.

Metal frame



Stiffness: 1100 N/mm

Composite with fully filled space

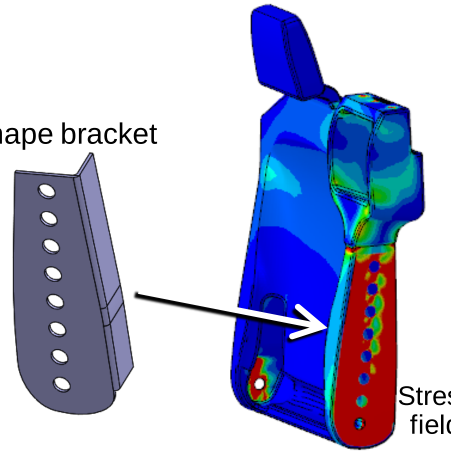


Stiffness: 260 N/mm (ABS/CF20)

Stiffness: 320 N/mm (PA/CF30)

- Modulus of steel: 200 GPa
- Modulus of PA/CF30 (x-direction): 19 GPa

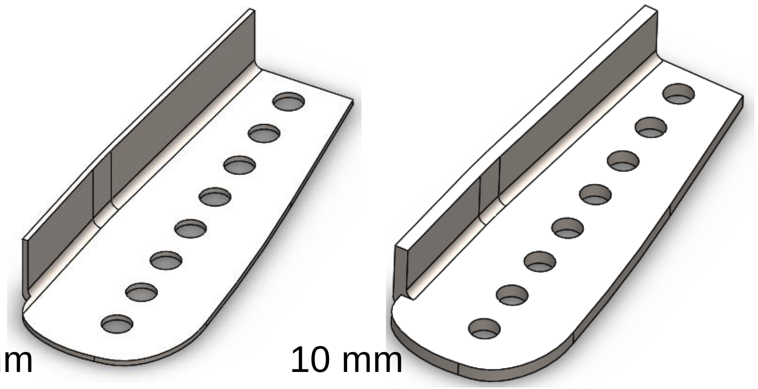
Metal insert + Composite



(PA/CF30)
Stiffness: 930 N/mm

Effect of L-shape bracket thickness

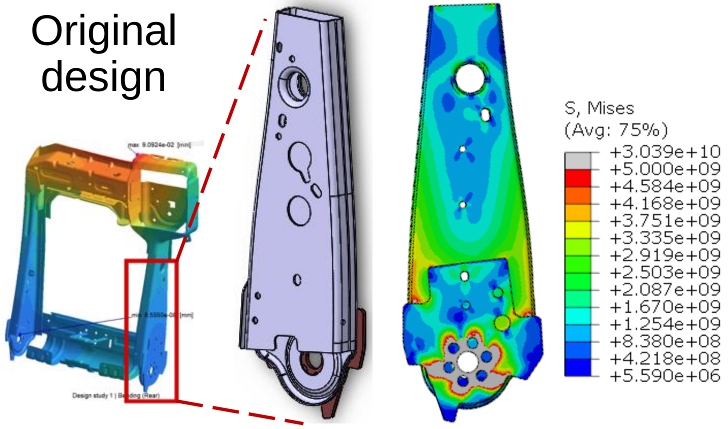
	Stiffness
4mm-thick	930 N/mm
10mm-thick	1640 N/mm



4 mm   10 mm

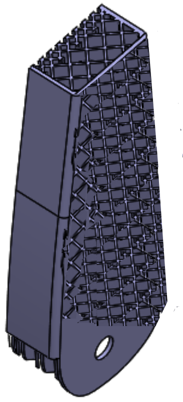
Accomplishments: Design Optimization – Composite + Metal Bracket

Original design

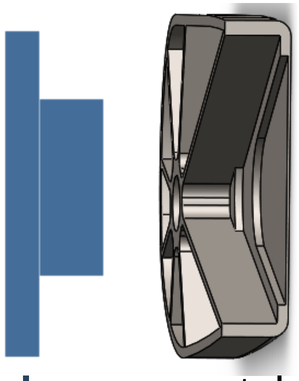


1.73kg 16.3 mm

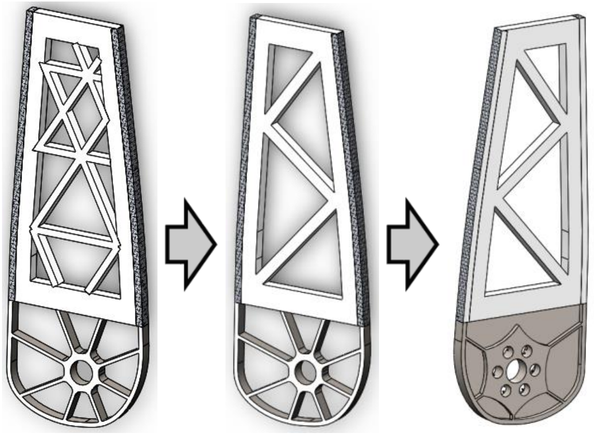
Introducing mesh



Overmolding

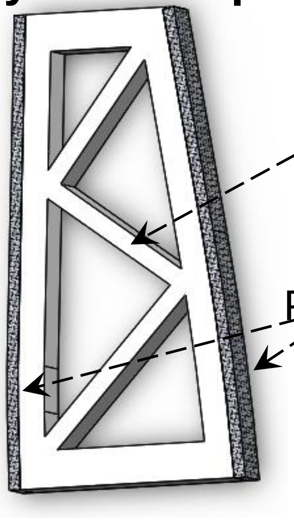


Polymer metal



1.45 kg
7.6 mm

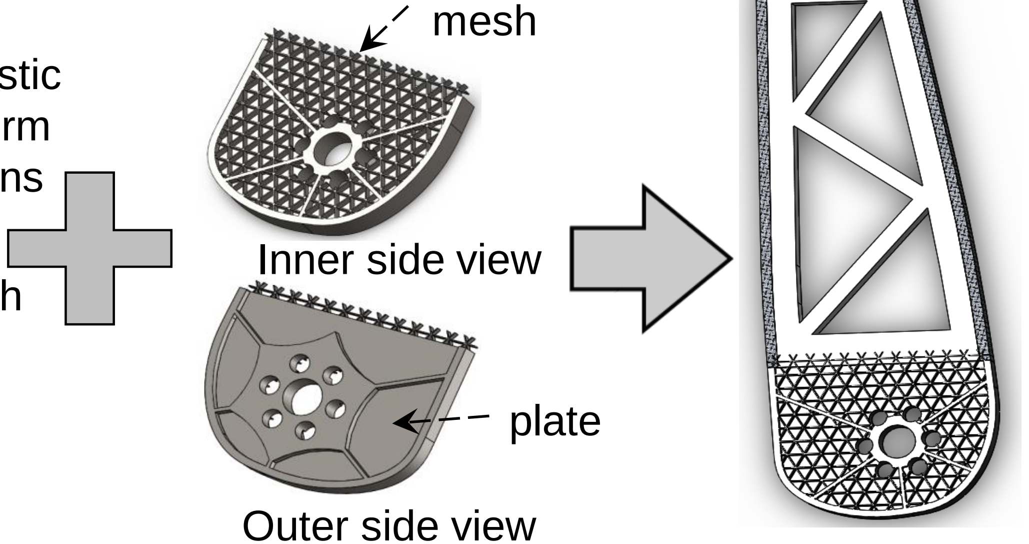
Polymer composite for overmolding



Long fiber thermoplastic made from AM preform with tailored directions

Polymer reinforced with unidirectional fibers

3D printed metal insert

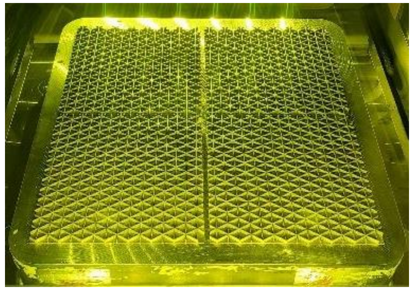


Outer side view

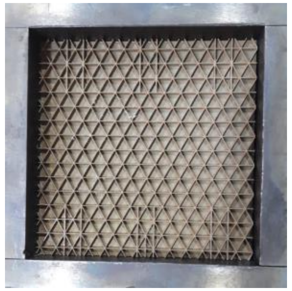
Accomplishments: Automation of AM polymer composite overmolding

- Previous approach:

Metal Mesh Additive Manufacturing



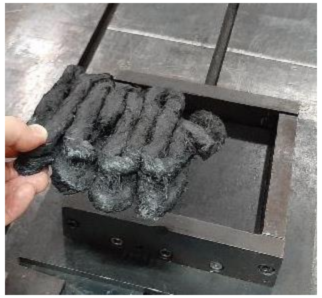
Laser Powder Bed System



Metal Mesh

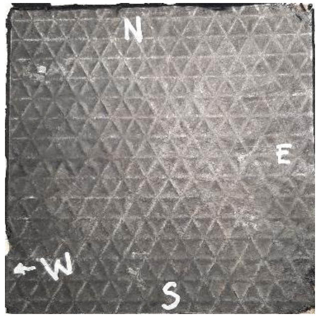
Long Fiber Thermoplastic AM

BAAM



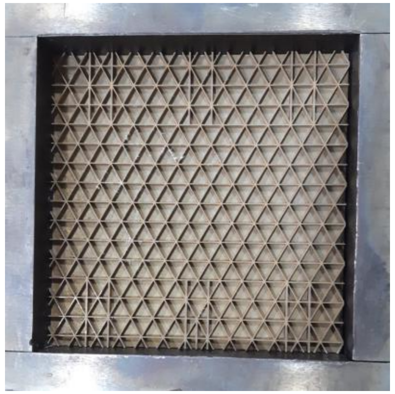
PA66/CF 40% CF

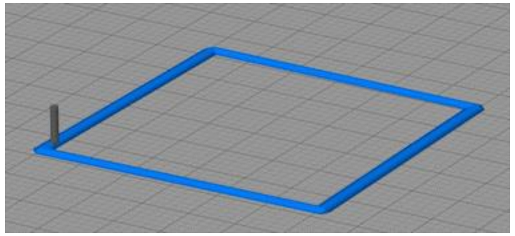
Overmolded Part



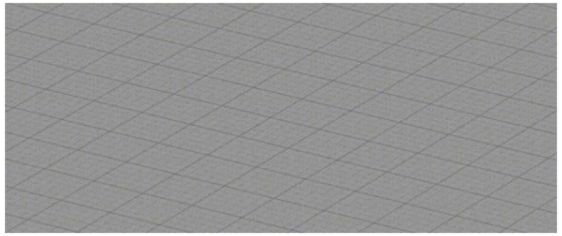
- Automation of AM Polymer Composite preform using AM-CM

Metal Mesh





Concentric Infill



Rectilinear Infill

6X faster visualization

Progress: Mechanical Characterization - Tension

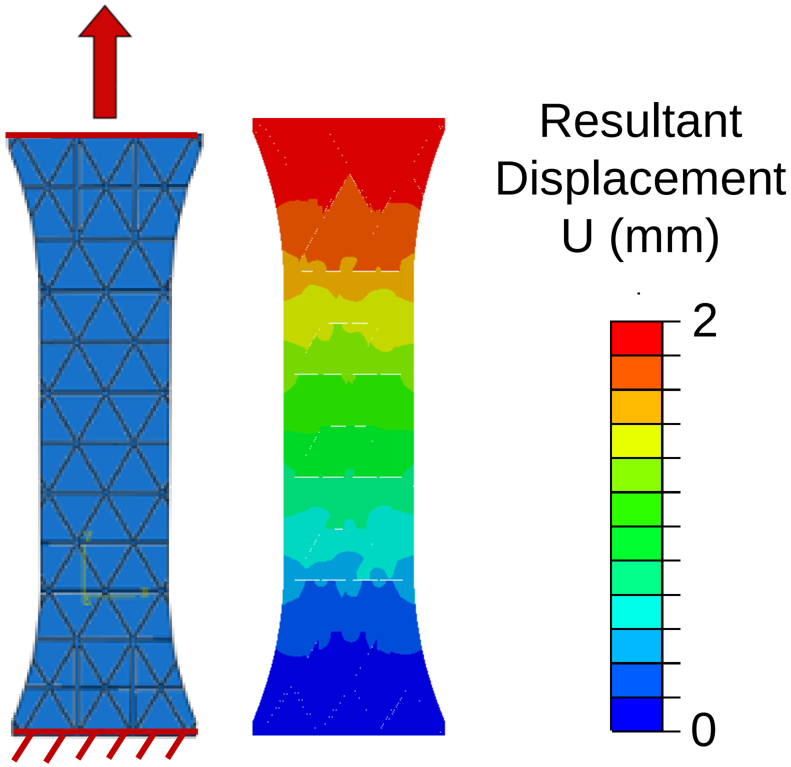
- Elastic modulus and tensile strength

Metal
- Maraging Steel (Elastic Modulus = 190 GPa)

Polymer Composite
- Long Fiber (0.5”) CF (40%) / PA 66

	Modulus (GPa)	Tensile Strength (MPa)	Failure strain (%)
Sample 1	8.49	70.12	1.15
Sample 2	9.57	83.5	1.21
Sample 3	9.25	75.5	1.27
Average	**9.1**	**76.37**	**1.21**

Average Elastic Modulus = **9.1 GPa**
(Experiments)

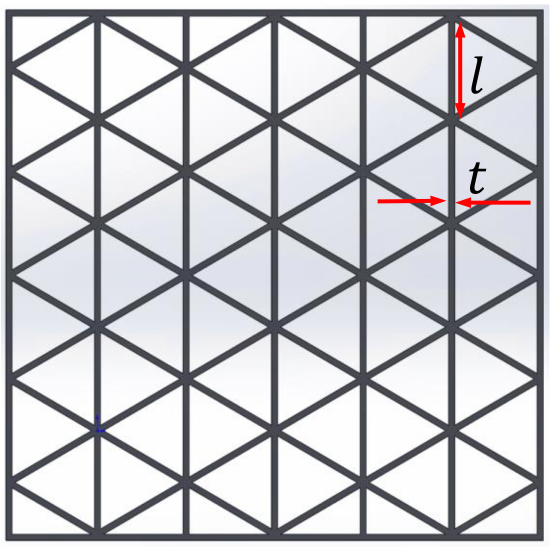


Elastic Modulus = **10.98 GPa**
(Numerical)

- Assuming 3D random fiber orientation (Isotropic)

Progress: Mechanical Characterization - Tension

- Elastic modulus prediction: Analytical Vs Numerical



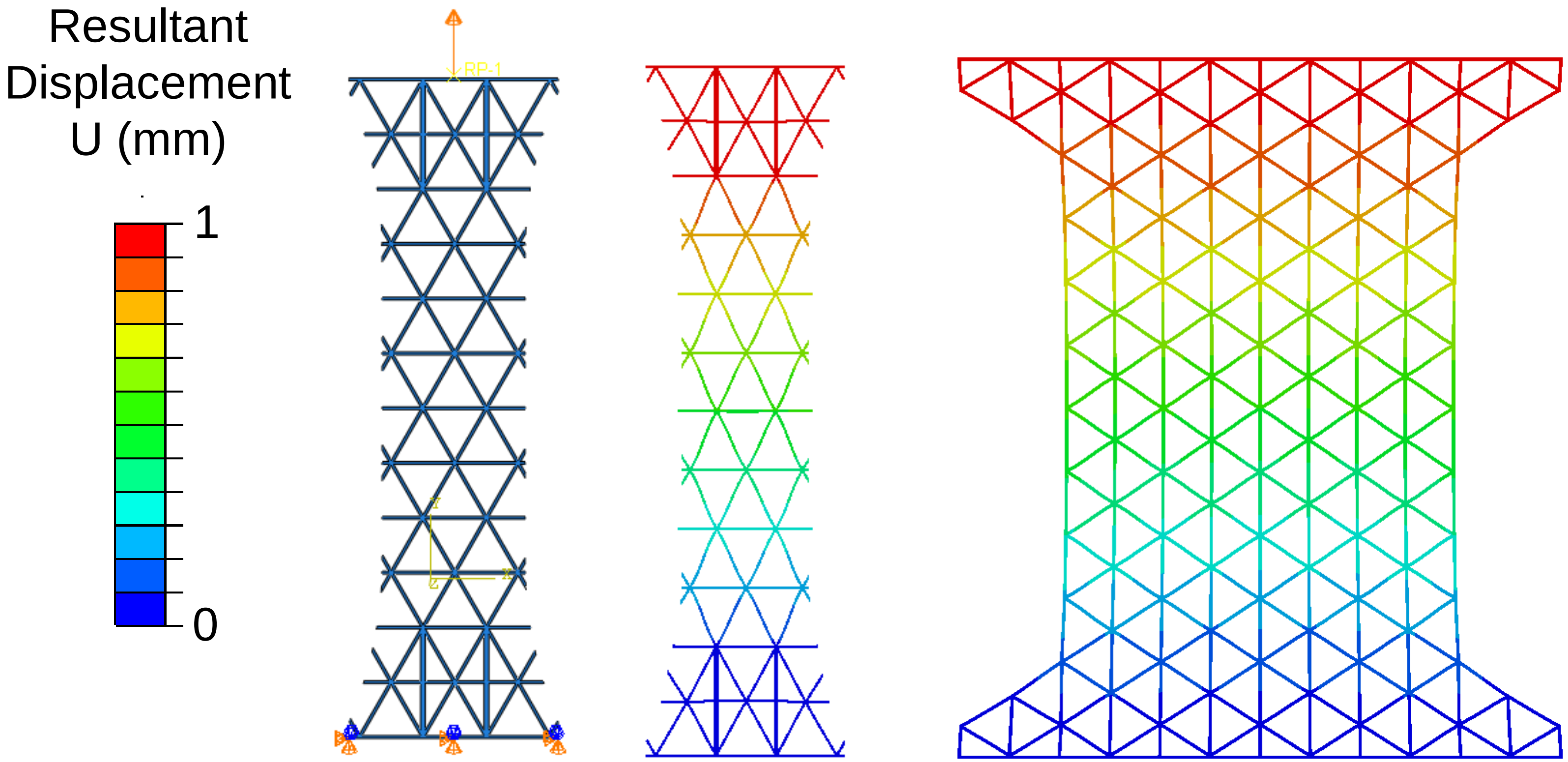
$l = 10\ mm \quad t = 0.6\ mm$

Relative density $(\bar{\rho}) = 0.2$

Maraging Steel(E_s) = **190 GPa**

Triangular lattice (E)= **13.1 GPa**

➢ Larger specimen (more unit cells) is necessary for a better prediction

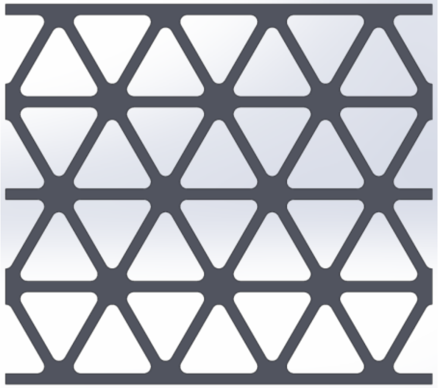


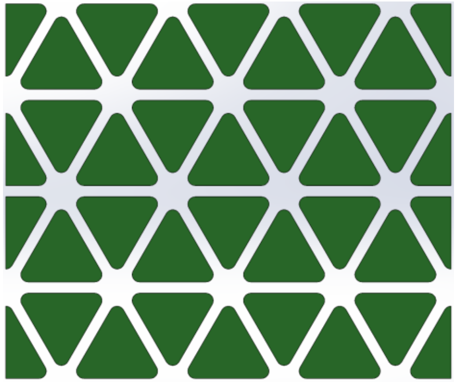
Elastic Modulus $= \mathbf{6.3\ GPa}$

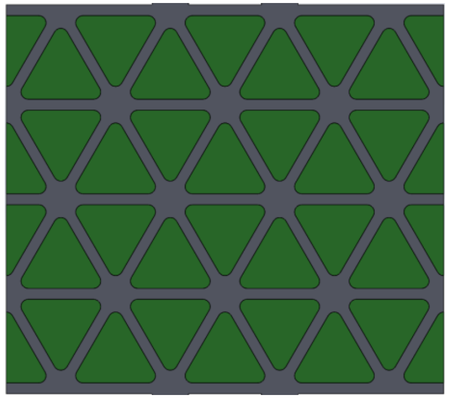
Elastic Modulus $= \mathbf{12.8\ GPa}$

Progress: Design Optimization of Hybrid Structures

- Previous Design

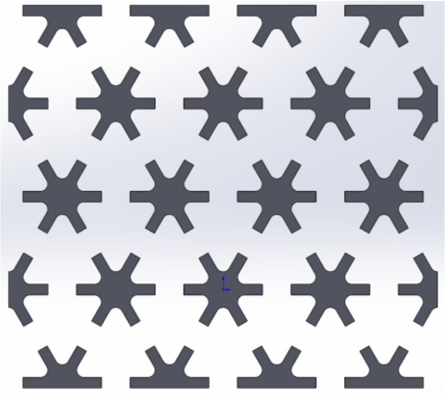

Metal Mesh

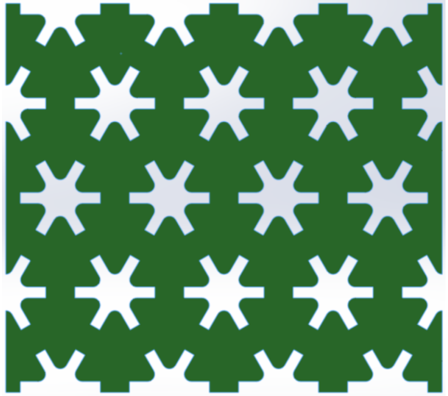

Polymer Composite

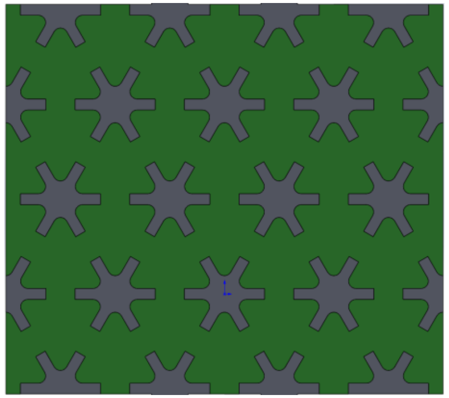

Hybrid Structure

➢ Polymer islands: Less interlocking between polymer and metal

- Lightweight hybrid structure with improved mechanical interlocking properties


Metal Mesh


Polymer Composite


Hybrid Structure

➢ Lightweight: less metal and more polymer
➢ Continuous composite channels
➢ More interlocking due to hooking action

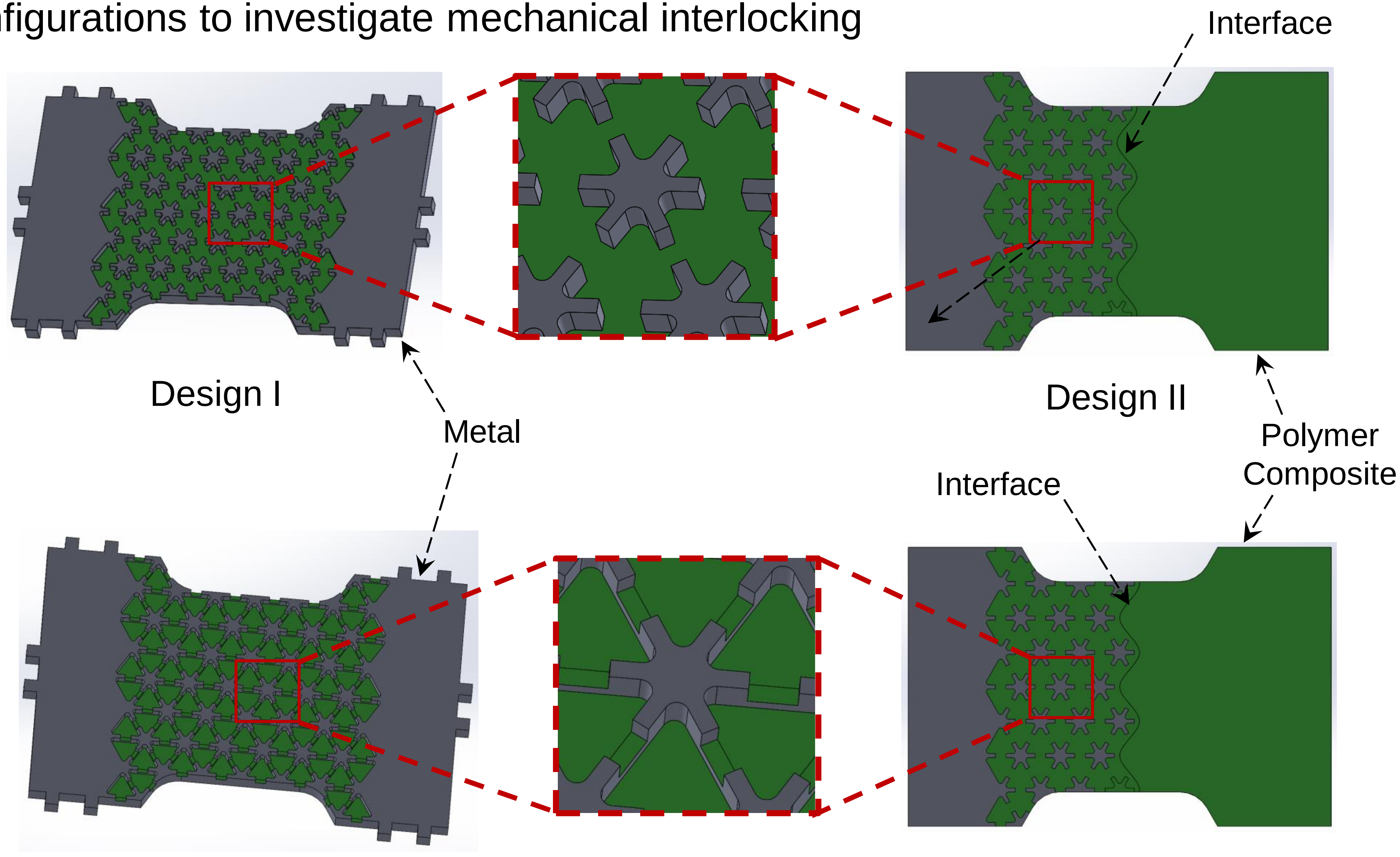
Progress: Mechanical Characterization - Tension

- Different channel configurations to investigate mechanical interlocking

(Full channel depth)

> ➢ Polymer composite is overmolded in the green-colored area

(Partial channel depth)



Design III

Design IV

Progress: Mechanical Characterization - Shear

- Shear testing along different planes of the hybrid structures

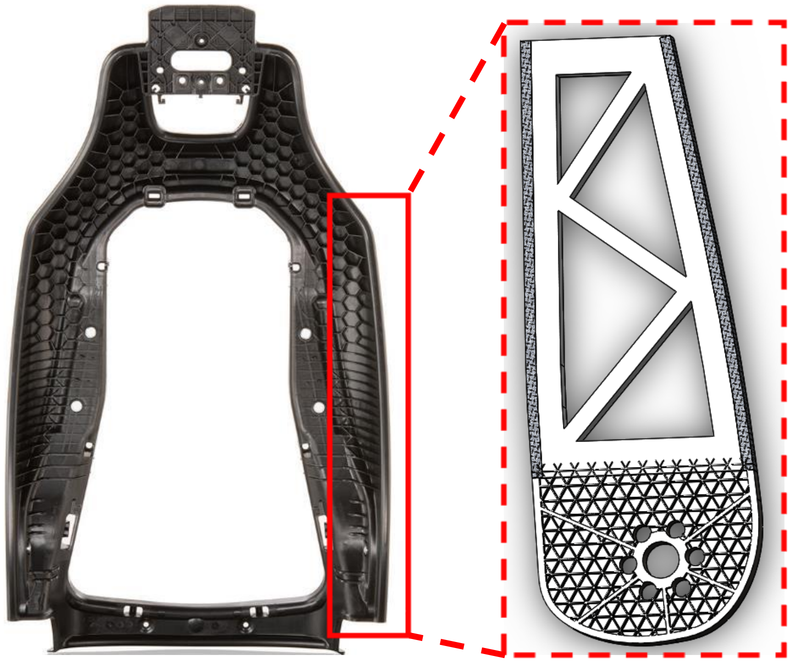
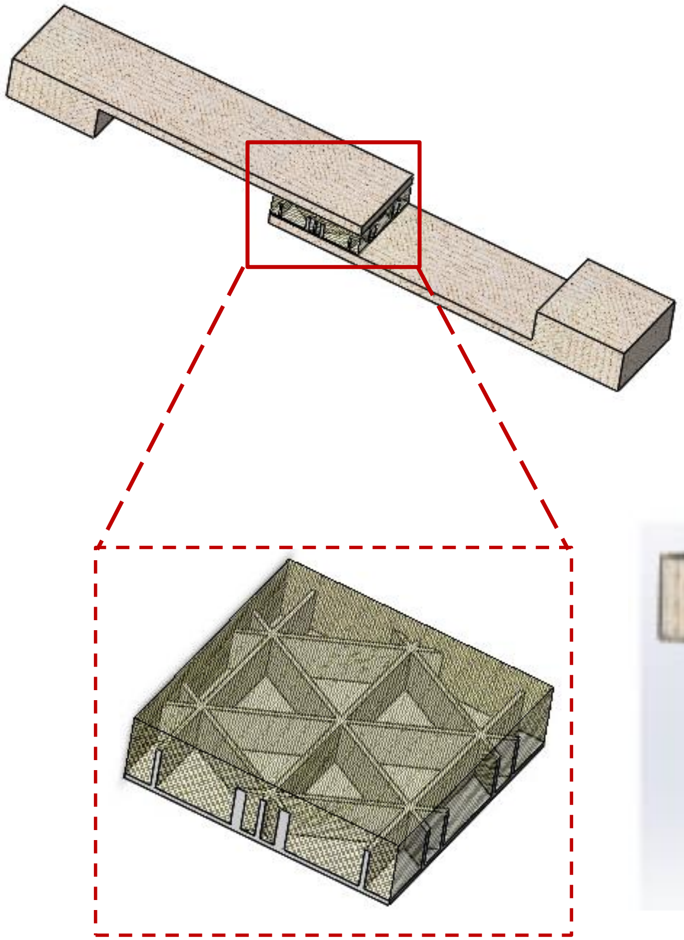
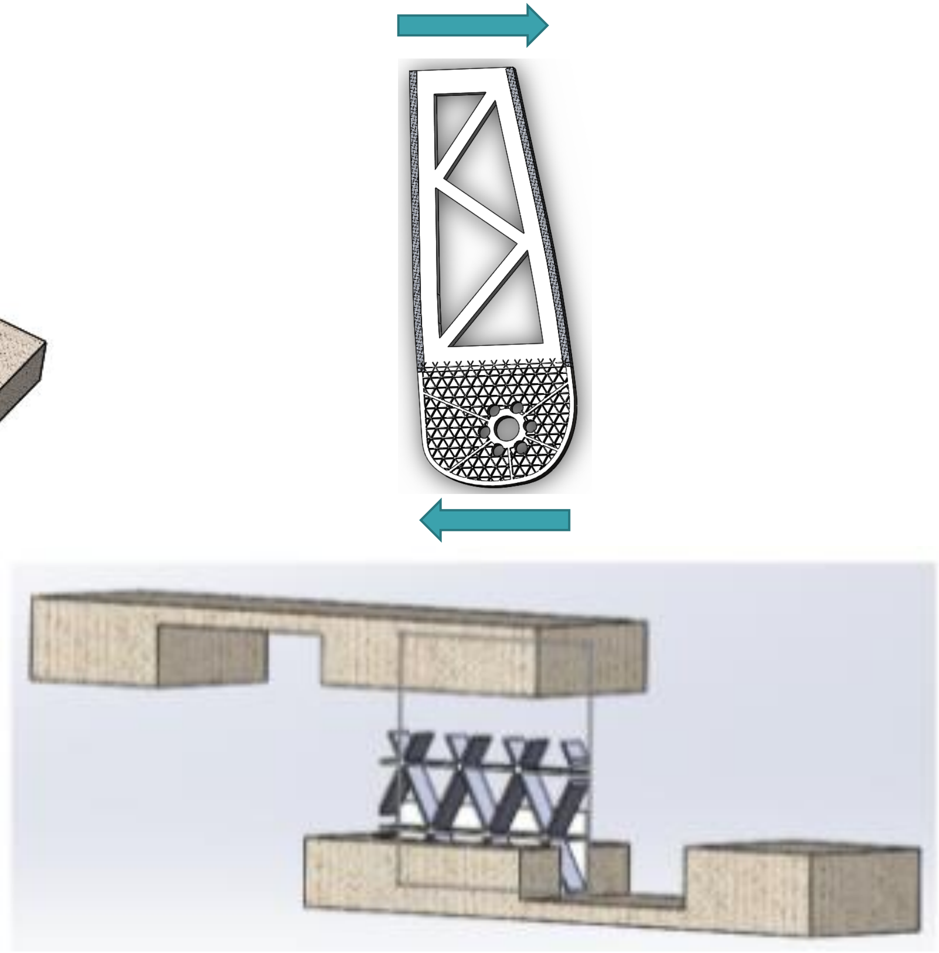


Image from: automotive.basf.com

Along the unit cell surface



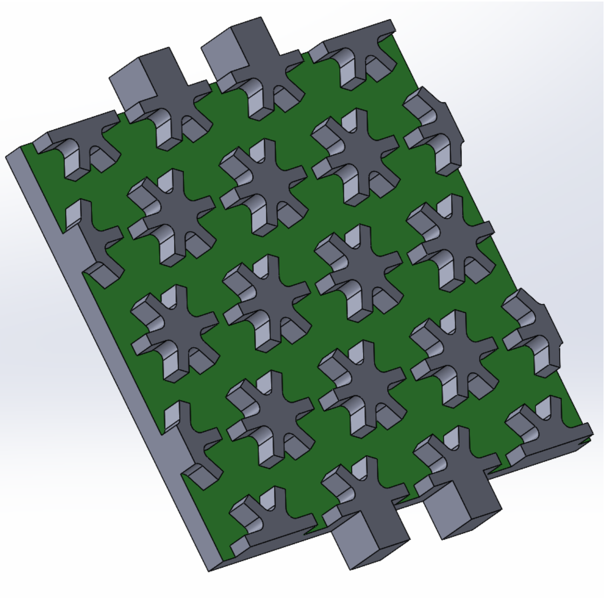
Across the unit cell



Progress: Mechanical Characterization - Shear

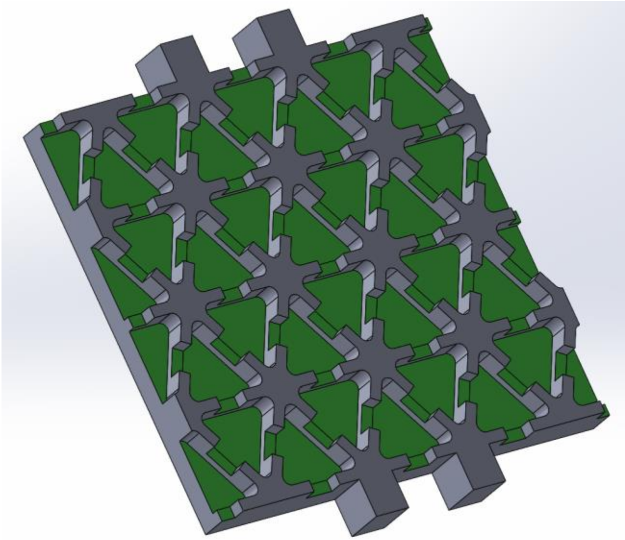
- Different configurations to investigate mechanical interlocking and interfacial bonding

Design I
(Full channel depth)



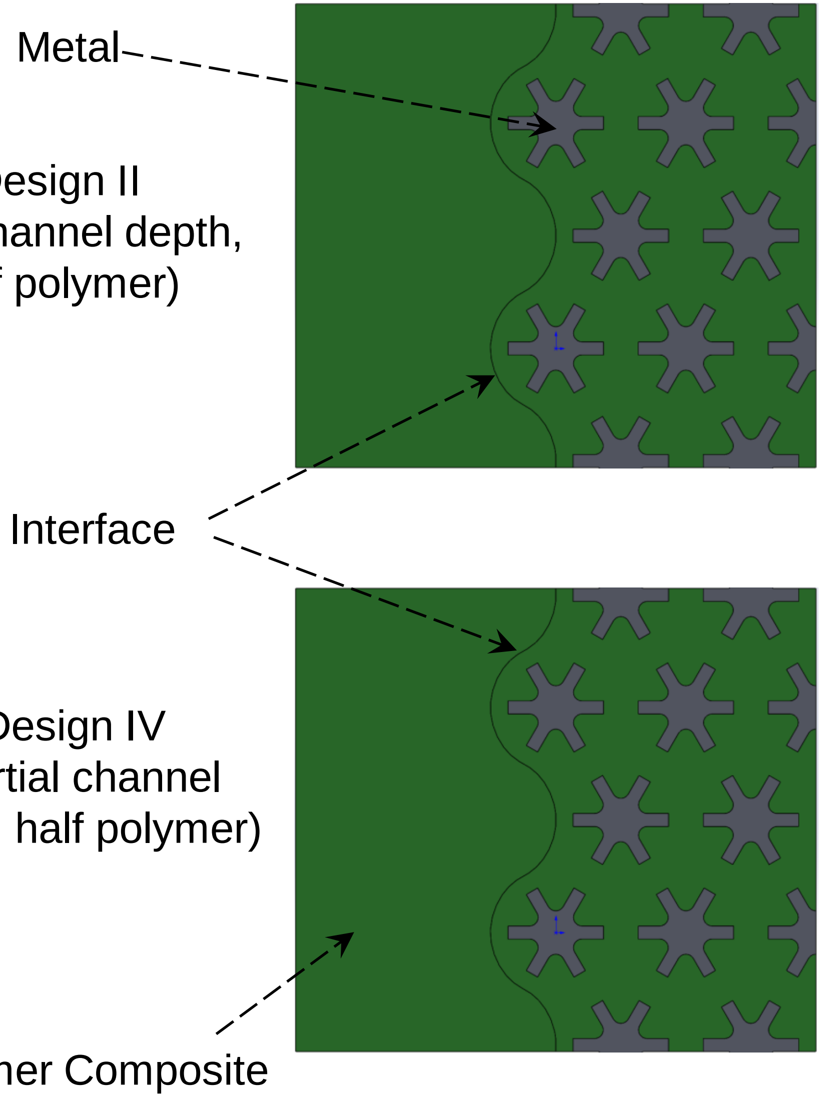
➢ Polymer composite is overmolded in the green-colored area

Design III
(Partial channel depth)



Design II
(Full channel depth, half polymer)

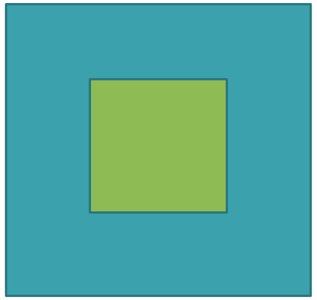
Design IV
(Partial channel depth, half polymer)

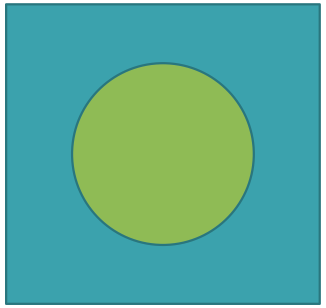


OAK RIDGE National Laboratory | MANUFACTURING DEMONSTRATION FACILITY

Progress: Custom AM Polymer Composite Overmolding

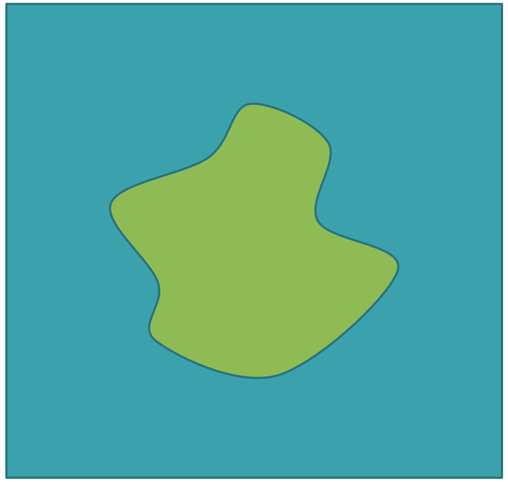
- Optimizing toolpath to enable overmolding on an arbitrary shape



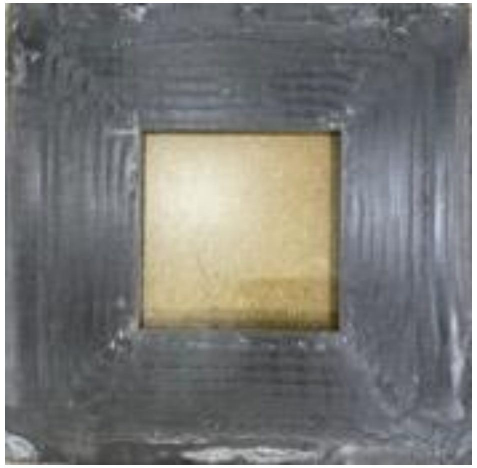


Mold

Composite



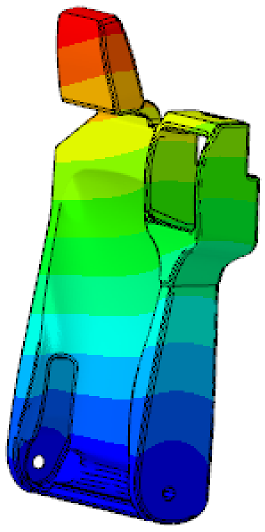
Custom part shape

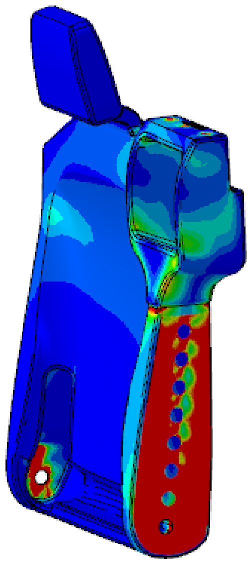


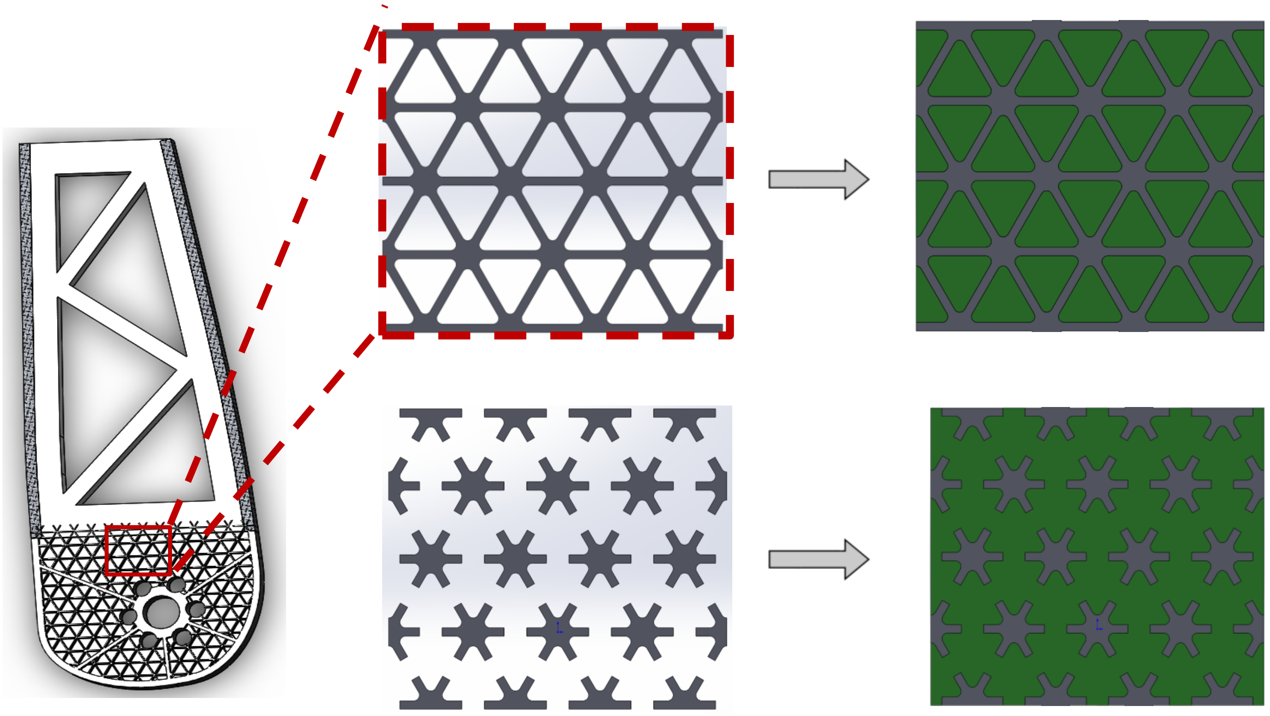
6X faster visualization

Responses to Previous Year Reviewer Comment's

The reviewer complimented this project for developing innovative manufacturing process of additive manufacturing of CF composites with metal inserts for lightweight seats. The reviewer inquired whether it is possible to add more CFs in the high stress area to replace metal inserts as this may further reduce the cost and weight







Previous design

New design

Displacement field | Stress field | Previous design | Metal Mesh | Overmolded Part

New design
- ➢ Lightweight: less metal and more polymer
- ➢ Continuous composite channels
- ➢ More interlocking due to hooking action

Collaboration

- Ford Motor Company
  - Point of Contact: Patrick Blanchard (pblanch3@ford.com)
    - Ford Project Team Members
      - Patrick Maloney, Sangram Tamhankar, Rao Parameswararao, Ari Caliskan, Marc Konrad, Kevin VanNieulande, Sean West
  - Technical Discussions:
    - Design review meetings for the metal/polymer hybrid structures
    - Inputs on cost effective AM process selection and it's challenges
    - Support on designing and simulations of seatback subcomponents and entire assembly

Remaining Challenges

- Understanding the mechanical behavior and characteristics of the over-molded samples
- Optimization of the seat back design with viability of manufacturing in mind
- Utilization of AM process for the manufacturing of the subscale mold

Proposed Future Research

- Mechanical testing and analyses of the overmolded samples (tensile, shear, interlayer)
- Reporting and documenting the findings – data will be used as an input for the FEA model
- Design modification of the subcomponent to satisfy the load/deflection criteria
- Complete a final assessment of the hybrid seat back design
- Demonstrating automation technology enabling to print and compress an arbitrary shape
- Exploring in-line integration of sensing and smart systems process monitoring. Data to be used within an Artificial Intelligence (AI) framework for manufacturing processes.

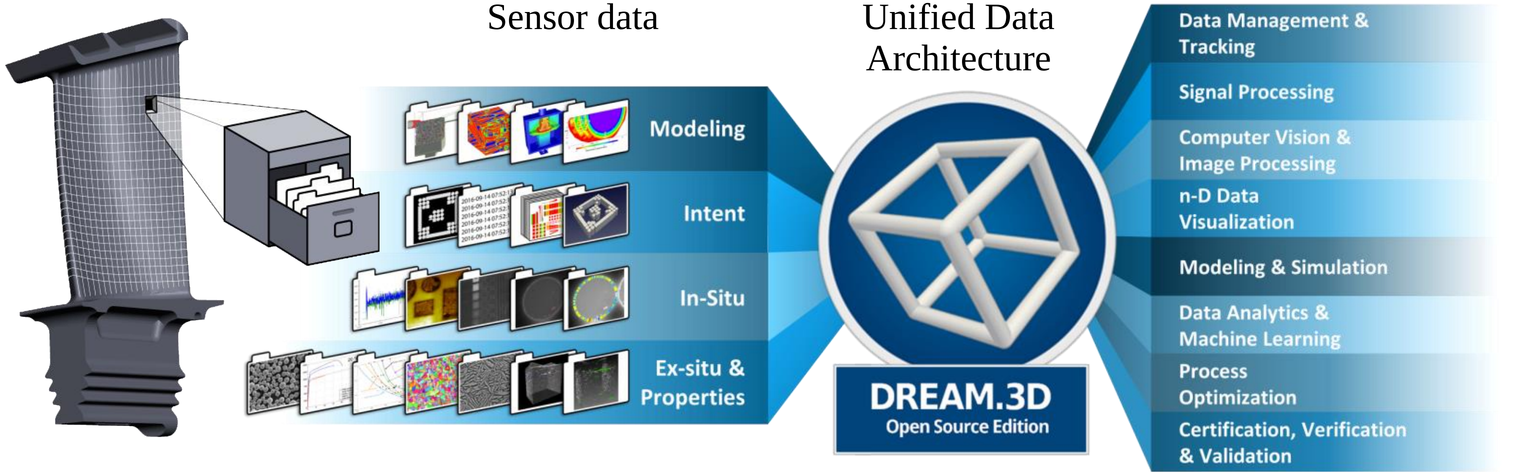
Any proposed future work is subjected to change based on funding levels

Proposed Future Research: Exploration of Sensing System and A.I. Framework

IT Infrastructure	Voxelized Parts	Data Producers	Digital Clone	Data Workflow
		Sensor data	Unified Data Architecture	

IT Infrastructure

- Wired network
- WiFi network
- IoT
- Storage systems
- HPC systems
- Embedded Systems



Cybersecurity

Digital Thread

- Integrate smart sensing system within AM Polymer Composite Overmolding to study relationship between processing parameters, material and final part quality.
- Explore data format for compatibility with the current AI platform at ORNL
- Use data analytics tools such as DREAM 3D to explore strong and weak correlations between material manufacturing parameters, composites processing parameters and final part quality
- Utilize previously developed framework developed primarily for metal AM

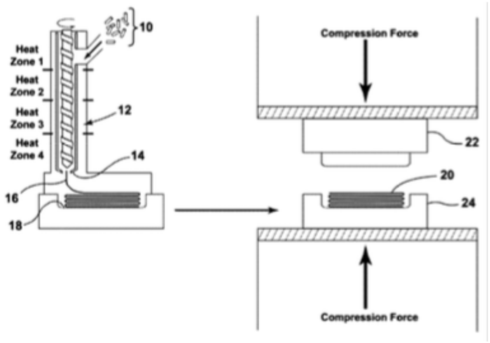
Summary

- Develop a novel manufacturing technique to produce lightweight car seats by combining AM and over-molding techniques
- Initial new seat designs, via topology optimization, that cannot be achieved through any other conventional processing methods
- Design optimization via FEA simulation – design modification
- Using AM to manufacture recliner metal brackets to be integrated with the composite preform via overmolding process
- Validation of the proof of concept of using AM mesh structures for joining in overmolded composites

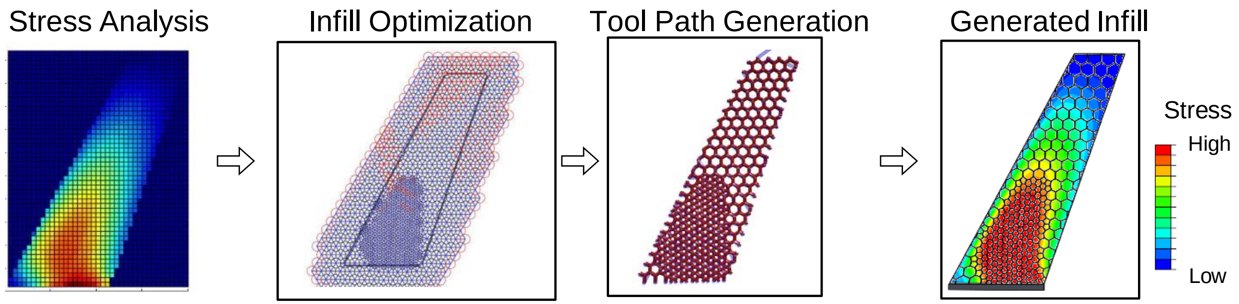
Technical Backup Slides

Relevant Invention Disclosures/Patents

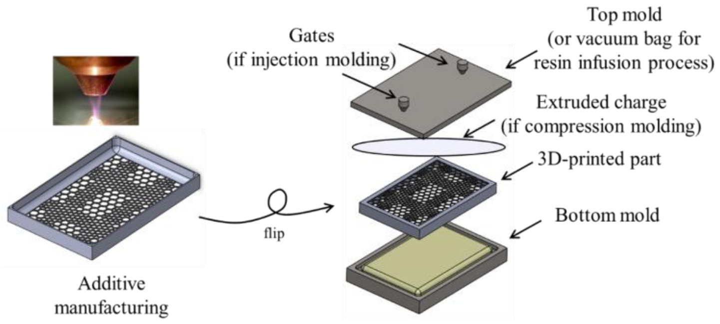
- UT-Battelle (UT-B) Invention Disclosure (ID) No. 4121, “Rapid manufacturing of tailored preforms”
- UT-B ID No. 3152, “Large Scale Polymer Additive Manufacturing and Carbon Fiber Layup Integration”
- UT-B ID No. 3151, “Method and Materials for Large Scale Polymer Additive Manufacturing”
- UT-B ID No. 201804272, “A Method for Rapid Manufacturing via Non-stop and Continuous Deposition in Additive Manufacturing by Adding Bridges in Toolpath”
- UT-B ID No. 202004563, “Overmolding on an Additively Manufactured Skeleton” (3)
- UT-B ID No. 201904506, “Graded Honeycomb for Additive Manufacturing” (2)
- UT-B ID No. 4278, “Manufacturing of insert skins for tooling”
- Patent US 2020/0023556 A1, “Rapid Manufacturing Of Tailored Preforms” (1)



AM – CM Process(1)



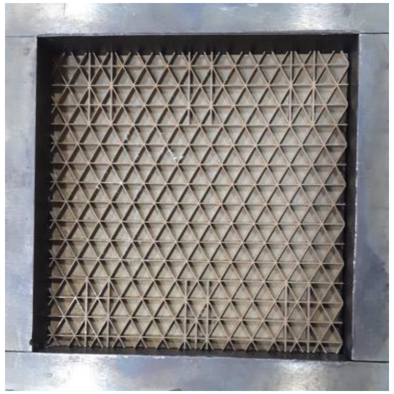
Graded Honeycomb (2)



Overmolding on an AM Skeleton (3)

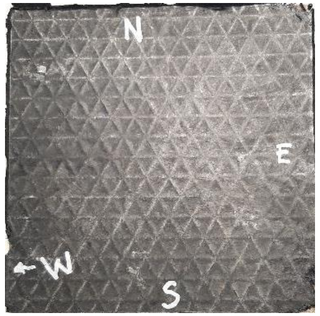
Accomplishments: Overmolding sample fabrication and bond testing

Metal Mesh



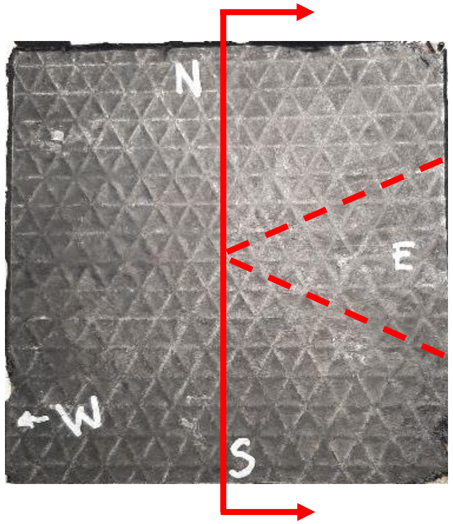
Polymer composite

Overmolded Part

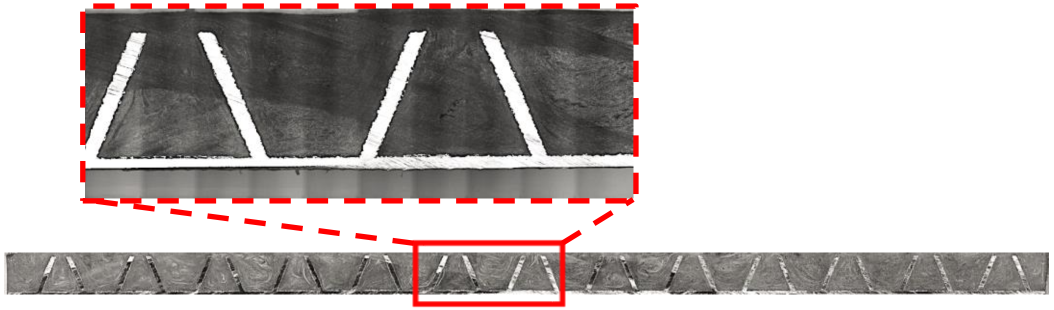


- Joined dissimilar materials through interlocking without a bonding agent

- Good flowability of the polymer into the mesh



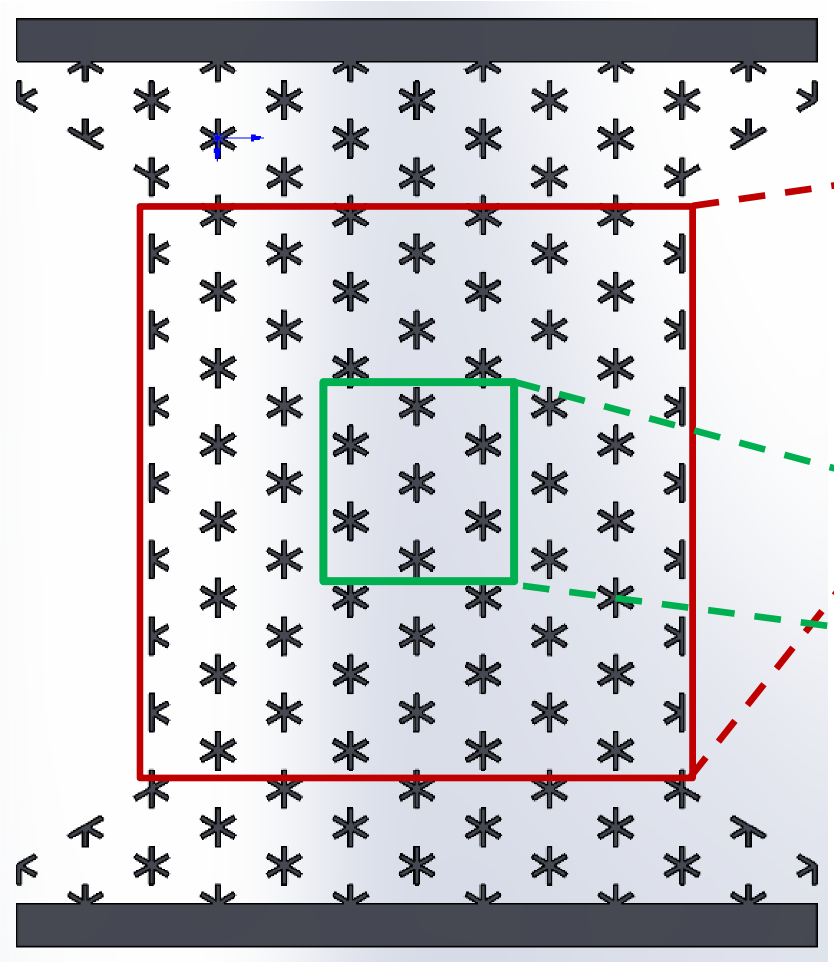
Cross section



Microscopic image

Progress: Tensile Testing Experimental Setup

- Experimental set up for tensile testing



Camera 1

Image from: limess.com

Camera 2

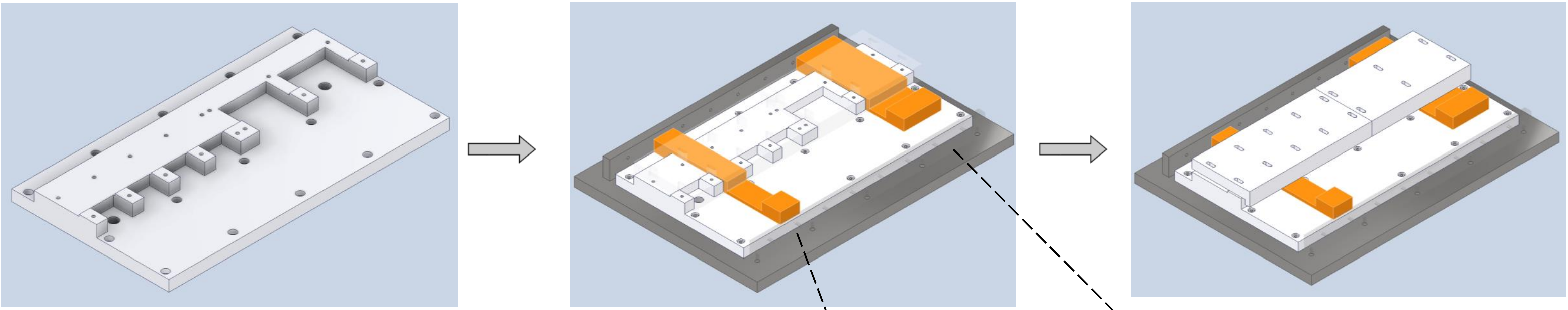
Image from: limess.com

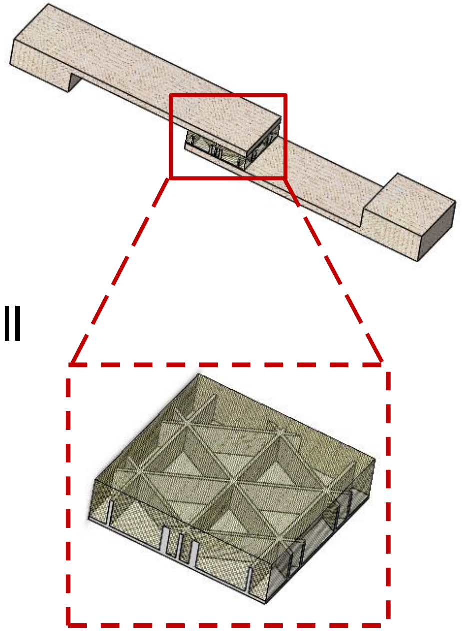
Strain Measurement using DIC

- Camera 1: Macro deformation tracking – Overall structure
- Camera 2: Micro deformation tracking – Unit cells at center

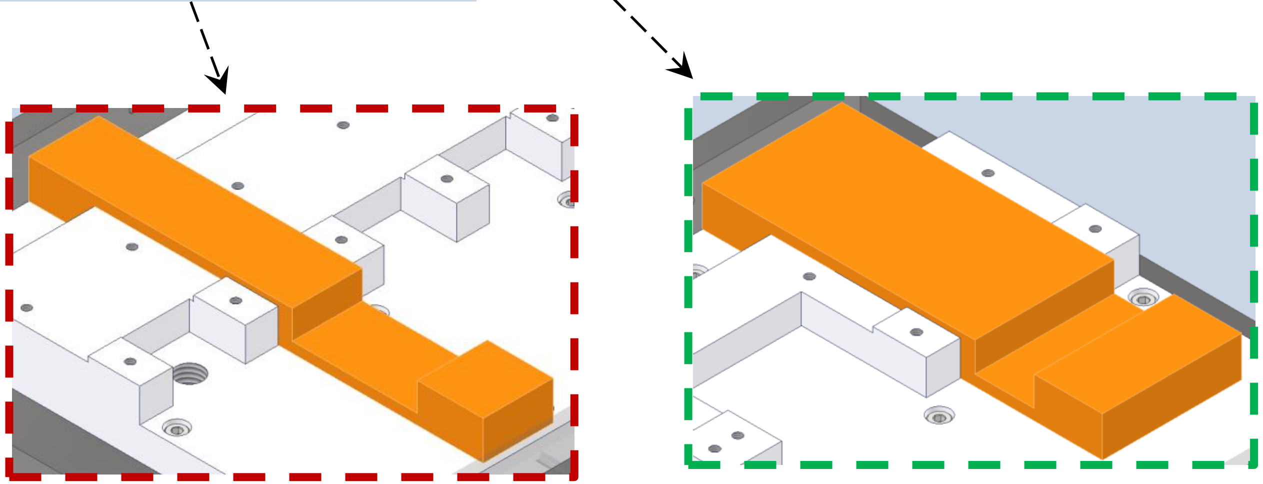
Progress: Mechanical Characterization - Shear

- Lap shear jig fixture designed for shear testing along the unit cell surface





Along the unit cell surface



Different sizes of lap shear specimens to investigate size effect